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The Case for a Mechanistic Model for Aquatic Ecosystems of the Bay/Delta

Sam Bledsoe, UC Davis

In recent weeks there has been considerable discussion of the merits, whys, and wherefores of integrative ecosystem models for the Bay/Delta. Some of this has taken place in the Estuary Ecological Teams meetings, some on the EET email reflector, and some at a panel discussion during the recent annual IEP meeting at Asilomar. The panel discussion followed Dr. Daniel Pauly's presentation on the results of his food web-based approach to analysis of resource status in a number of the world's marine fishery systems.

I've been a consistent advocate of the value of a mechanistic ecosystem model as a research tool in the Bay/Delta and I'd like to clarify, as concisely as possible, what kind of tool I am advocating and what I think will be its value. I should make clear in the beginning that, in spite of the terminology used above, this is not really *a* model, in the sense of a single computer program which is all things to all ecologists, but rather a computerized, theoretical framework or model system which has the capability to be configured to study a very broad variety of aquatic ecological circumstances.

I'm thinking about a computerized mathematical tool which projects a time series of its state variables from an initial starting point (just like the hydrodynamic models) and has the following characteristics.

1. Variable spatial resolution which can focus on a single area regarded as homogenous (e.g., Suisun Bay) or on multiple areas each with unique characteristics and which communicate materials and biota.

2. Strong interface to existing hydrodynamic models which are currently in use for water management decision making (but not necessarily tied to a single such model or version) and which can provide certain essential environmental driving variables (temperature, salinity, DO, current, etc.).

3. Broad temporal dynamic range, i.e., intraseasonal, multi-seasonal, multi-year, or long-term (e.g., 50 years), depending upon configuration.

4. State variables of the system as (meta-)population densities (numbers/area) and biomass (grams carbon) indexed (variably) by age, species, and geographic location, and carbon (detrital) densities indexed by size. (Optionally, additional state variables may include various body constituents of organisms, such as trace isotopes or contaminants, and other non-living ecosystem constituents besides carbon—N, PCBs.)

5. Incorporation of the known ecological mechanisms and their interrelations which are operational in animal populations (e.g., feeding, growth, reproduction, mortality and other processes related to viability and death), configured according to the most appropriate sources of information and/or hypotheses under investigation.

6. Mechanisms are responsive to physical (e.g., temperature, salinity, turbidity) and biological (e.g., predator and food density, space for attachment), environmental variables as provided by the hydrodynamic driver and other mechanisms of the system, configured according to the most appropriate sources of information and/or hypotheses under investigation.

If such a research tool were to be undertaken, a guiding principle would be to build upon existing information about the ecosystem. The model system would be capable of both building upon this knowledge as well as testing it. This seeming paradox is possible because the model system in any given configuration is regarded as a complex hypothesis. Its projections may immediately contradict known information, in which case parts of the hypothesis (once logical errors are ruled out) are suspect—knowledge has been tested. Otherwise, its projections are subject to direct or indirect verification through the usual empirical methods—

knowledge has been used to design research. Finally, if enough confidence exists in a desirable projection of the system (i.e., the model is validated) then the management actions to bring about that result might be proposed—research results in practical application. This is a gross simplification but should illustrate the main idea.

Here are a few sources of existing information which should be incorporated in any early configurations:

1. The existing suite of known or suspected X2 relations among the environment and organisms (Interagency Technical Report 52, Jassby et al. 1995);

2. The relationships of the Food Web Conceptual Model (Interagency Technical Report 42, Estuarine Ecology Team 1995);

3. The feeding relations identified among zooplankters (Interagency Technical Report 41, Orsi 1995);

4. The information concerning historic salinity preferences and abundances of aquatic animals (Interagency Technical Reports, as updated by more recent surveys).

In cases where there are neither existing known or suspected mechanisms (e.g., larvae of certain species have never been collected) it is necessary to make a plausible, consistent assumption (perhaps several alternative assumptions) about what is happening and incorporate it into the model configuration. A strong statement about that assumption in the configuration documentation should be made. After all, the entire model is a hypothesis. While this may limit some applications of the model projections, it may equally turn out to be irrelevant or it might even shed light on what is actually happening in the system or direct research appropriately. In any event, the objective is to gain a projection of probable future dynamics of the system as a whole; it is important to not allow small details to obstruct that goal.

A common objection to this research approach is that there are "too many unknown mechanisms." In the Bay/Delta ecosystem the first challenge is to incorporate the enormous amount of mechanistic information that is available. It will be a considerable challenge to do justice to simply the information in the above four enumerated sources. The bibliography of ecological information that the EET is currently compiling is a vast resource which covers, together with information referenced therein, enough material to construct several very respectable and useable configurations of a Bay/Delta ecosystem spatial model with both species population and biomass density resolution. It is absolutely impossible to know whether there are "too many unknown mechanisms" without

doing the exercise. In any event, this is a question without a single answer—there certainly will be uses for model configurations for which there are plenty of data, and it certainly will be possible to ask questions of the system for which critical information will be, in the final analysis, missing. However the exercise will likely help to direct the appropriate research. The more relevant question is "What alternative approach can make use of the vast amount of ecological information which is available and direct the collection of further information?"

Here are two of the specific potential values and uses of such a research approach, in addition to those generic advantages pointed out above:

1. A configuration of this model system could be used to project zooplankton responses to various flow configurations in a range of water years. While some aspects of such a projection could be done based on empirical regression relations, this approach would not be dynamic or responsive to interactions among system components. It would also be incapable of extrapolation to novel conditions, such as exotic invasions. In short, it would not be an ecosystem approach. To use the dynamic model approach would require a considerable investment of time and effort, but the result would be a truly dynamic and interactive picture of zooplankton dynamics. This would be subject to the usual model caveats about assumptions and hypotheses, however, the regression method is also subject to such caveats. The inductive approach cannot hope to give the kind of detailed insight into the mechanistic operation of the system, based on an order of magnitude more data, that is possible with a mechanistic dynamic model.

2. A similar dynamic picture of fish population responses could be made. Since the model system would not include events occurring in the ocean, those population variables are driving functions of the system. For a range of variation due to whatever causes off the coast, a configuration of a Bay/Delta model could project the range of influence of factors within the modeled system. For striped bass, for example, causes of population fluctuation both within the Bay/Delta and extraneous to it have been proposed. It seems to me that it would be extremely valuable to have an objective tool with which to investigate the consequences, interactions, variability with weather, and other factors of these causes in a holistic ecosystem context.

Finally, let me comment on the degree of detail required for, and the predictability of, this approach. The specification calls for bioenergetic, population, feeding, physical environment, etc., mechanisms all in the same

model. These are necessary because these mechanisms are always working—they are the fundamental equations of the ecosystem. In any given time and place not all of them will be simultaneously equally important in determination of the dominant dynamics of a particular state variable. However, although empirical data can sometimes give an indication of which have been important at particular areas of the state space of (time, place, species, etc.), it is impossible to second-guess which will be important in the future. If some of these mechanisms are unimportant in a particular analysis, then the analysis will show it. I have seen criticisms that food web models show the food web to be important because the model emphasizes the food web. The point is to build a model which places appropriate emphasis on all the mechanisms influencing the variables of interest where "appropriate" is determined by knowledge of the system.

Model predictions in a system as proposed will likely be subject to "critical sensitivity to parameters and initial conditions"—what this means is that the system dynamics will sometimes be "chaotic," or highly variable, like a computer's random number generator. Does this mean that the system will not be predictable? No more or less so than reality is, ultimately, predictable. What it does mean is that those aspects of the real ecosystem which are predictable can potentially be captured reliably by this approach. If specific population values at specific times and places are not predictable, then patterns, frequencies and envelopes of variability likely will be predictable, and the model will also predict exactly how likely. Even a random number generator follows a distribution function and has frequency characteristics. I look at a weather prediction model on the Internet almost every day (http://wxp.atms.purdue.edu/maps/eta/eta_pres_4panel.gif) and sometimes its right and sometimes not. However the pattern of weather which it predicts is virtually identical to the pattern which I experience—in that sense this ecosystem model will have prediction capability.

The development and configuration of a research tool of this complexity is something which no one person can accomplish— it requires too many different disciplines of knowledge and must be responsive to too many varieties of analysis. A team approach is needed. The management of that team must be capable of mobilizing its resources and simultaneously avoiding the pitfalls of "design by committee". That calls for, in addition to a lot of hard work, a critical mix of willful self-determination and sacrifice of ego and opinion by the team members. The EET and the community of researchers, engineers and managers involved in the Bay/Delta certainly have the expertise to accomplish the task.

Romberg Tiburon Center Introduces New Staff

Alissa J. Arp, RTC Director, San Francisco State University

Many readers of this newsletter are probably familiar with some of the work that has been done at the Romberg Tiburon Center for Environmental Studies (RTC). RTC is an academic research and educational facility on San Francisco Bay operated by San Francisco State University. In particular, Wim Kimmerer and Steve Obrebski of RTC and Tim Hollibaugh, formerly of RTC and now at the University of Georgia, have been involved in numerous IEP projects. The purpose of this article is to introduce you to some of the other RTC researchers, our teaching activities, and some of our plans for the future of the center.

RTC is in a formative stage, revitalized and energized by new researchers and increased university and grant support. Much has happened in the last few years—we have attracted new scientists, increased the number of graduate students on site to 18, intensified our coastal research and course offerings, broadened and strengthened our ties to our community, and initiated work on our physical facility that will allow us to continue our momentum.

RTC scientists Richard Dugdale and Frances Wilkerson, both NSF, ONR- and DOE-funded biological oceanographers who recently joined us from USC, wrote a paper for *Nature*. In that paper, they laid out their explanation for the widespread and puzzling oceanic condition in which plankton productivity remains low despite high nutrient levels. The paper, based on research in upwelling waters of the equatorial Pacific, appeared in the January 15 issue, along with a companion review from a prominent German oceanographer.

Steve Bollens, a newly-hired Associate Professor of Biology and currently an ONR Young Investigator, is a zooplankton ecologist and fisheries oceanographer formerly of Woods Hole Oceanographic Institution. Steve made national news last fall when he reported on the status of a study he and East Coast researchers are carrying out as part of the GLOBEC program. They discovered that tiny predatory hydroids are floating by the millions off a large region of the New England coast, where they compete with, and perhaps prey upon, cod and haddock larvae.

Neo Martinez, a recently hired Assistant Professor of Biology, from the University of California at Berkeley (UCB), is a theoretical ecologist studying food web structure. While much of his work in this area is theoretical and synthetic, part of his research involves developing biomolecular techniques that would enable empiricists to identify and quantify gut contents using DNA signatures. Neo was recently invited to become an affiliated member of the Energy and Resources Group at UCB.

Iceworms resided at RTC for awhile after David Julian, RTC postdoctoral associate from UCSF, and I returned from a NOAA-sponsored expedition to the Gulf of Mexico last summer. The worms turn out to be a new species living on toxic methane ice mounds. Our research group focuses on the ecological physiology of marine invertebrates living in challenging environments such as these hydrocarbon cold seeps, deep sea hydrothermal vents and sulfide-enriched estuarine mud.

Our newest RTC scientist is biological oceanographer Bill Cochlan, who just joined us in March from USC by way of the Antarctic. His focus on microbial ecology and physiology is a great complement to our existing strengths at the larger phytoplankton and zooplankton level. Bill's NSF funded research will carry on the strong tradition of expertise in microbial ecology established during Tim Hollibaugh's time at RTC.

Wim Kimmerer continues in his roles as chair of the IEP Estuarine Ecology Team, lead PI of the Entrapment Zone study, PI of a study of the zooplankton of the lower estuary, and participant in the Yolo Bypass study. He has provided a long history of expertise in biological oceanography, with particular emphasis on zooplankton ecology and computer modeling.

Steve Obrebski, an aquatic ecologist and population biologist, has been associated with RTC since 1985 and has been a strong contributor to the educational program both in the classroom and as a research mentor. He is currently working with RTC scientists Trish Foshi, Terry Irwin, Mike McGowan, and graduate student Jennifer Pearson, on a California Department of Boating and Waterways funded project to study the biological effects of controlling the invasive weed *Egeria*, which blocks important waterways, greatly increasing the costs of pumping water in the San Francisco Bay/Delta.

Mike Josselyn, Professor of Biology, continues his state-funded studies to establish the viability of restoring wetlands to stabilize both the physical and biological condition of the bay. Mike maintains an active research program receiving grants and contracts from federal and state agencies to investigate issues on wetland restoration effectiveness, wetland and riparian habitat management plans, and general wetland ecology.

We are currently conducting a search for a tenure track faculty member with expertise in physical oceanography who will be based at RTC but associated with the Department of Geosciences on the main campus. We're looking for a scientist with a strong field component to their research who has experience working in coastal waters and an interest in estuarine processes. Someone with a focus on transport processes, such as particle/organism transport, will add considerable strength and round out the RTC team. Three additional tenure track hires are planned over the next few years.

Our research vessel the R/V Questuary underwent a recent engine upgrade and we were recently awarded a $99,000 NSF-Field Stations and Marine Laboratories (FSML) grant, matched with $25,000 from SFSU, to upgrade scientific and navigational equipment on shipboard. Ship time is a hot commodity, as the boat is heavily used for collecting bay specimens, water sampling, and for other research and classroom uses. A previous NSF-FSML award is funding the renovation of the old Commodore's residence on site into a Guest Center which will house visiting scientists and students in the future.

Our education mission is to provide undergraduate and graduate courses in biology, geography, and geology that promote learning in the fields of marine and estuarine biology and ecology, oceanography, and limnology. There is also a growing summer education program that provides introductory and general interest courses for the surrounding community. We have increased the breadth of our course offerings to our SFSU students and have added a shuttle service from the main campus. We have also added new summer courses such as Plant Communities of Marin County, Biological Oceanography, and Aquatic Toxicology.

This year, we are celebrating our 20th anniversary and are gearing up to enter a major capital campaign, scheduled to begin this fall. An award from the Marin Community Foundation will help us launch a professional feasibility study, and we will be hiring a Director of Development to add life and direction to the campaign effort. Our goal is to shape and implement a capital